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ABRUPT INITIATION OF THE COLORADO RIVER AND INITIAL INCISION OF THE GRAND CANYON

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The Grand Canyon is by far Arizona's most well known geologic feature. Over 4 million visitors each year gaze into the canyon and marvel at its beauty and immensity. While the rocks in the canyon record much of the geologic history of northern Arizona over the past 1.8 billion years, they reveal little about why the canyon exists. Of course, the Grand Canyon was cut by the Colorado River. Why is the Colorado River here? When did it get here? Why has it cut such a deep canyon? How did all of the sedimentary rocks in the walls of the canyon, many of which are marine in origin, get to such high elevations? These and related questions, which have challenged geologists since John Wesley Powell first floated down the Grand Canyon in 1869, are the subject of this article.

The logo of the Arizona Geological Survey (AZGS) includes a small map of Arizona divided into three regions. The northeastern region is the Colorado Plateau, an area characterized by gently inclined layers of sedimentary rock that are especially well displayed in prominent cliffs and in deep canyons. The Colorado Plateau extends across much of adjacent Utah, Colorado, and New Mexico. For hundreds of millions of years, this region was intermittently inundated by shallow marine water, but sometime in the past 80 million years it was uplifted to present elevations of roughly 1500 to 2500 meters (5000 to 8000 feet). Adjacent areas, including the Rocky Mountains and western Great Plains, were also uplifted, but by lesser amounts. Much of the puzzle about the origin of the Grand Canyon concerns the cause and timing of the great uplift that brought the rocks of the Colorado Plateau from near sea level to their present elevations. This uplift must have occurred without the associated faulting and igneous activity that typically occur in mountain ranges during uplift.

The Colorado River leaves the Colorado Plateau at the Grand Wash Cliffs where it flows into Lake Mead (Figure 1). A long, north-south trending valley at the foot of the Grand Wash Cliffs, known as Grand Wash trough, contains lake sediments that were deposited between about 11 and 6 million years ago. While the lake sediments were being deposited, alluvial fans derived from highlands on both sides of the valley were deposited on the flanks of the valley. There is no evidence in these sedimentary rocks of a large river like the modern Colorado entering the valley. Indeed, if the modern Colorado had entered the valley, it would have quickly filled the lake with sand and gravel. A volcanic ash bed near the stratigraphic top of the limestone is 6 million years old, so the Colorado River must have arrived in this area after this time.

Figure 1. High altitude view of the mouth of the Grand Canyon, Grand Wash Trough, and Lake Mead. (Image provided by Dr. William A. Bowen - California Geographical Survey - http://geogdata.csun).

South of Lake Mead the Colorado River traverses 400 km (250 mi) of low desert before arriving at the head of the Gulf of California south of Yuma. Deposits of the Bouse Formation record a brief but deep inundation of basins along the course of the river (Figure 2). The Bouse Formation consists of a basal layer of silty limestone that is typically one to several meters thick and is commonly overlain by up to hundreds of meters of siltstone and minor sandstone. These sediments were thought to have been deposited in an estuary of the developing Gulf of California after a U. S. Geological Survey (USGS) paleontologist first reported the presence of marine invertebrates in 1960. Estuaries generally have variable salinity conditions because, during times of high river flow, fresh water dilutes the salt water while sea water is dominant in times when river input is low. This leads to a mix of marine, brackish, and fresh water organisms like those represented by the fossils in the Bouse Formation.

The Bouse Formation is exposed at elevations of up to 536 m (1760 ft), with elevations generally increasing from south to north. If in fact the Bouse Formation was deposited in an arm of the sea, then the lower Colorado River trough must have been uplifted by up to 536 m in the past 5 million years. USGS geologist Ivo Lucchitta proposed in 1979 that not only was the lower Colorado River trough uplifted in the past 5 million years, but that this uplift was part of a more regional tectonic uplift that carried the Colorado Plateau up to its current high elevation.

Three discoveries in the past 10 years have cast doubt on the interpretation that the Bouse Formation was deposited in an estuary. In a paper published in 1997, Professor P. Jonathan Patchett of the University of Arizona and Jon Spencer of the AZGS showed that the strontium isotope composition of Bouse Formation limestone was similar to that of Colorado River water, and quite different from sea water. They proposed that the Bouse Formation was deposited by the Colorado River in a series of lakes that filled with river water and spilled over, eventually linking the river with the Gulf of California (Figure 3).

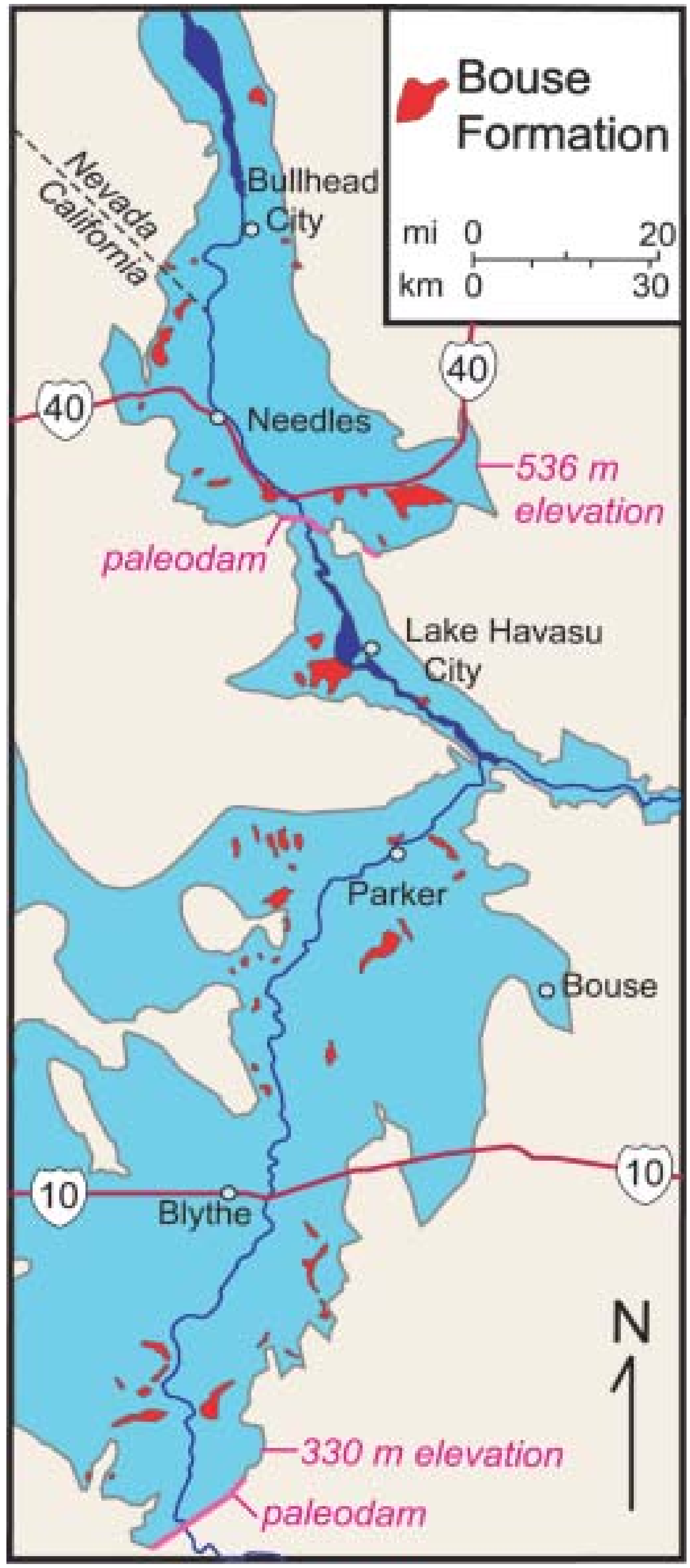

Figure 2. Map showing the distribution of outcrops of the Bouse Formation along the lower Colorado River trough. Pale blue color represents the maxium extent of lakes during deposition of the Bouse Formation.

In 2002, during the course of a field mapping project in the Bullhead City–Laughlin area (Mohave Valley), Kyle House of the Nevada Bureau of Geology and Mines and Phil Pearthree of the AZGS discovered evidence that initial inundation of the northern part of the Colorado River trough was marked by southward-transported flood deposits. Such flood deposits would not be expected for initial inundation from sea water derived from far to the south, but they are consistent with an upstream lake spillover and initial influx of Colorado River water derived from the north in the Lake Mead area. These flood deposits are directly overlain by the basal limestone of the Bouse Formation. On the flank of the valley, they found a volcanic ash layer just below the Bouse Formation that was determined by Mike Perkins of the University of Utah to be 5.5 million years old. Bouse deposition was succeeded by a period of erosion, which was followed by deposition of at least 250 m (800 ft) of sand and gravel that is clearly associated with the Colorado River. This period of massive river aggradation ended about 4 million years ago, as another volcanic ash was found near the top of the river deposits. Yet another volcanic ash indicates that the Colorado River had downcut at least 60 m (200 ft) below the level of maximum aggradation by 3.3 million years ago.

Most recently, Rebecca Dorsey of the University of Oregon and co-workers reported at the fall 2005 annual meeting of the Geological Society of America that Colorado River sands first arrived in the Salton Trough south of Yuma 5.3 million years ago. Such sands would have been deposited before reaching the Salton Trough if any large body of standing water such as a lake or an estuary existed along the course of the Colorado River. The sand deposits thus reveal the existence of a through-going Colorado River by 5.3 million years ago and mark the beginning of an enormous influx of river sediment that has filled the Salton Trough since that time.

All of these recent studies are consistent with the concept that the Bouse Formation was deposited in a geolog-

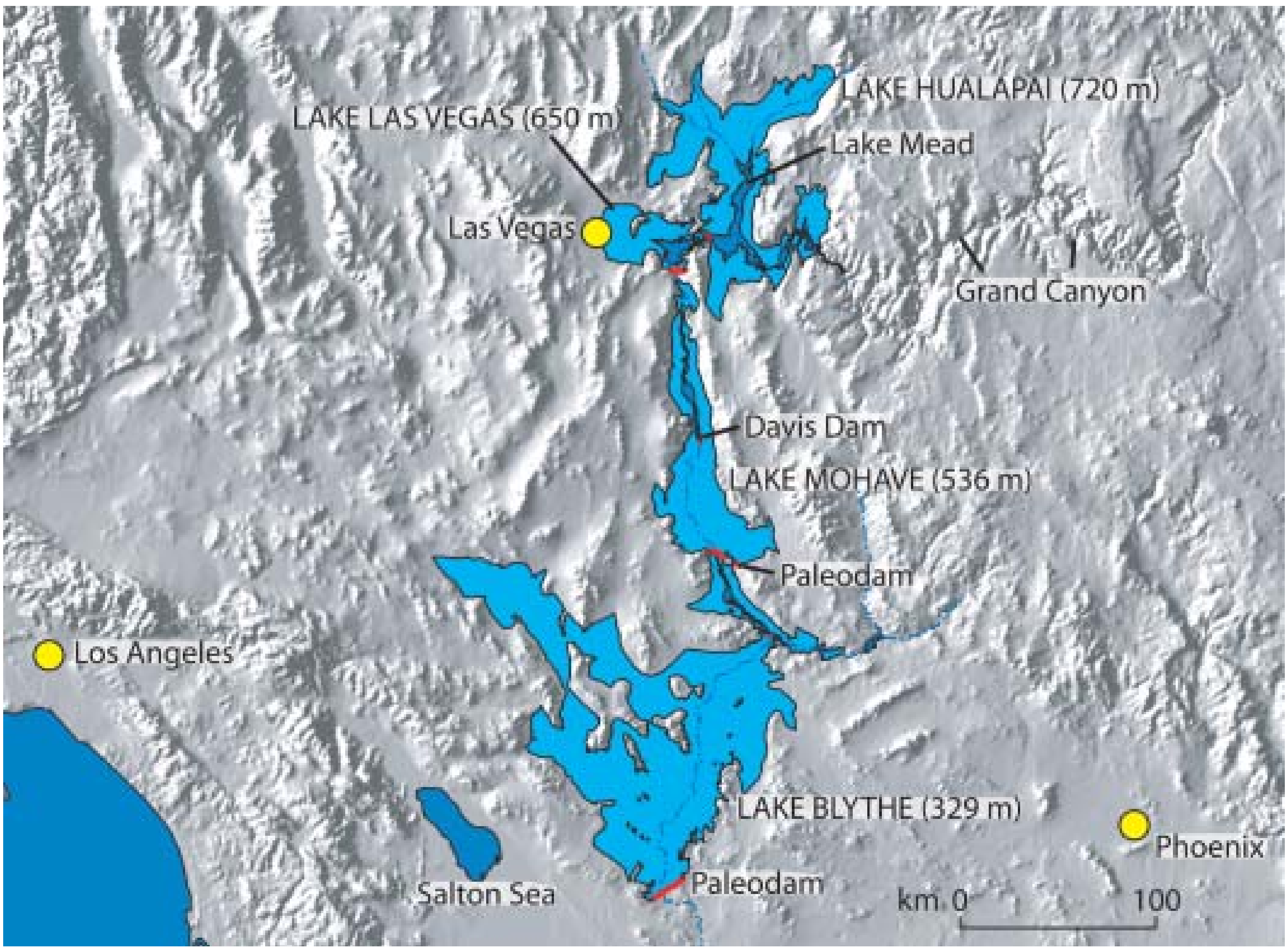

Figure 3. Lakes and paleodams during deposition of the Bouse Formation. Not all of these lakes could exist at one time because the combined surface area is so large that evaporation would remove all the water before it reached the downstream lake. Most likely, upstream lakes filled, spilled, and shrank as outflow incised a channel and lowered lake level. Downstream lakes eventually filled and spilled as upstream lakes shrank and evolved into river channels.

ically short-lived chain of lakes that were created by initial influx of Colorado River water into previously closed basins. At the mouth of the Grand Canyon, the Colorado River first arrived less than 6 million years ago. Along the course of the lower Colorado River, it appears that all of the Bouse Formation was deposited between 5.5 and 5.3 million years ago and Colorado River sands arrived in the Salton Trough less than two hundred thousand years after deep flooding of Mohave Valley. The influx of Colorado River water and sediment at this time marks the inception of the modern Colorado River. Tens to possibly hundreds of meters of river sand and gravel were deposited in Mohave Valley and elsewhere in the lower Colorado River trough in the subsequent 1 to 1.5 million years, as a tremendous volume of river sediment accumulated in the Salton trough. This massive aggradation probably resulted from rapid erosion in the Grand Canyon as the Colorado River downcut through that region.

The studies mentioned above have created a new problem for geologists. What are we supposed to make of the marine and estuarine organisms in the Bouse Formation? These organisms require salty water, but have been found only in sediments of the southernmost of the basins in which the Bouse Formation was deposited (the large Blythe sub-basin). Recent calculations show that evaporation in the southernmost lake as it was filling with river water could have elevated salinity to sea-water levels. The organisms, however, would have to be carried from the sea to the lake and delivered in sufficient numbers to provide a reproducing population. This seems like an impossible task, but long distance transport of aquatic organisms by birds has been documented in a number of places. And, if the Colorado Plateau was not uplifted during the past 6 million years, when was it uplifted? Various other types of evidence for age of uplift are contradictory, and this issue remains unresolved.

In conclusion, the abrupt arrival of the Colorado River to the low western desert region as a series of lakes roughly coincides with the beginning of incision of the Grand Canyon. Before this time, water that flowed off of the west slope of the Rocky Mountains and into the interior of the Colorado Plateau must have terminated in a lake on the Plateau or exited the Plateau along an unknown route. We think it most likely that cutting of the modern Grand Canyon began with spillover of a very large lake in northeastern Arizona and rapid incision of the lake outflow point about 5.5 million years ago. Details of the spillover and development of the Colorado River through Grand Canyon are not known, but we suspect that it involved catastrophic flooding and rapid erosion. As the Colorado River propagated downstream through the Basin and Range province, it sequentially filled, spilled over, and drained a series of formerly closed basins, eventually linking with the Gulf of California by 5.3 million years ago.

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Lee Allison to be new Director of the Arizona Geological Survey

Dr. M. Lee Allison, Science and Energy Policy Advisor to the Governor of Kansas and former Director of the Kansas and Utah Geological Surveys, will become Arizona State Geologist and Director of the Arizona Geological Survey sometime in December.

Lee Allison is Science and Energy Policy Advisor to Kansas Governor Kathleen Sebelius, on loan from the University of Kansas. He is also executive director of the Kansas Energy Council, which serves as the primary energy policy and planning arm for the state. At the request of Governor Sebelius, he organized a task force to find balance in the highly contentious dispute over wind energy development in the Tallgrass Prairie areas of the Flint Hills.

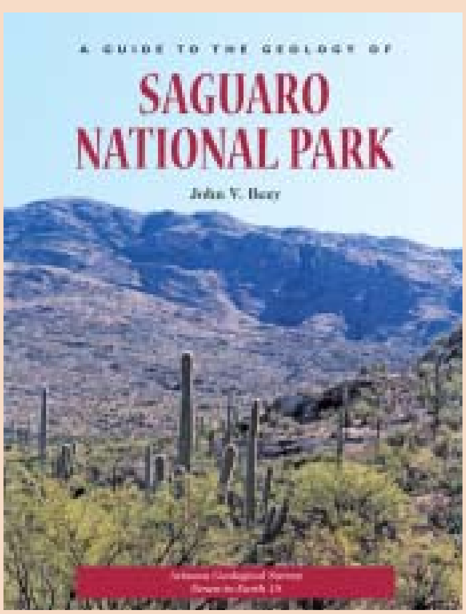
He previously was State Geologist of Kansas and Director of the Kansas Geological Survey for five years. Prior to assuming that position in 1999, he served as State Geologist of Utah for nearly 10 years. Dr. Allison holds a B.A. from the University of California, Riverside; an M.S. from San Diego State University; and a Ph.D. from the University of Massachusetts, Amherst, all in geology. He worked in petroleum exploration and production throughout the U.S. as well as in geothermal exploration.

He served five years on the Kansas Water Authority which sets state water policy, and is the founder of the High Plains Aquifer Coalition, an association of science institutions in eight states that addresses scientific and technical issues affecting groundwater in the region.

During the past few years he has advised the National Science Foundation on designing and building the national cyber-infrastructure and currently chairs the Earth Science-Cyber-Infrastructure Forum. He is a member of the National Research Council's Board on Earth Sciences and Resources.

He has given more than 140 presentations to civic, scientific, and legislative groups around the country. He is the author of over 80 technical publications and dozens of editorial columns. He received the national Public Service Award from the American Association of Petroleum Geologists in 2002 for his leadership in a variety of controversial issues in the geosciences. The Association for Women Geoscientists presented him the Tanya Atwater *Encourage* Award in 2003 for promoting the role of women in the profession. The murder mystery *Fault Line* by Sarah Andrews is loosely based on his role in dealing with earthquake hazards affecting Olympic facilities in Salt Lake City.

AZGS Releases New Book on Saguaro National Park



The Arizona Geological Survey recently released *A Guide to the Geology of Saguaro National Park*, written by John V. Bezy, as Down-to-Earth 18.

Saguaro National Park offers a variety of spectacular geologic features. This booklet is a field guide to the geology of this magnificent desert and mountain landscape for both the East (Rincon Mountains) and West (Tucson Mountains) Districts. Because of the relatively sparse vegetation in the lower elevations of the park, most of these features are easy to recognize and photograph.

Most of the geologic features described can be reached by short hikes from the tour roads of the park. This booklet is written for the visitor who has an interest in geology, but who may not have had formal training in the subject. It may also help ensure that the visiting geologist does not overlook some important geologic features.

This 36-page booklet is in full color in an 8.5" x 11" format and sells for $7.95. Ordering information is provided on the last page of this issue of Arizona Geology.

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Mark Your Calendar

The Tucson Gem and Mineral Society will present the Tucson Gem and Mineral Show February 9-12, 2006 at the Tucson Convention Center. The show, largest of its kind, features gems, minerals, jewelry, and gifts. Dealers from the U.S. and many other countries will be present.

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